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Harmonic Control Based on Fuzzy Logic

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Abstract

Proliferation of nonlinear loads in power systems has increased harmonic pollution and deteriorated power quality. Passive filtering has typically been the standard technology for harmonic and reactive power compensation .With the advancements in power electronics, active filtering is being more widely considered given its flexibility and precise control. However, cost, complexity, and reliability are considered the major drawbacks of active filters. In this paper a new fuzzy logic is introduced to control the harmonic in the power system, which has more advantages such as simplicity, ease of application, flexibility, speed and ability to deal with imprecision and uncertainties .The introduction of fuzzy logic can not only reduce harmonic ,but also correct the power factor.

Keywords: Fuzzy logic, fuzzy sets, harmonic control, power factor

1. Introduction

In today's power systems, the proliferation of nonlinear loads has increased harmonic pollution. Harmonics cause many problems in connected power systems, such as reactive power burden and low system efficiency. Harmonic distortion is becoming a growing problem that needs to be addressed with the proliferation of nonlinear loads in many residential, commercial, and industrial applications. Several active and passive harmonic filters have been investigated to satisfy the power quality standard [1-2] for the deployment of nonlinear loads. Passive filtering has been preferred for harmonic control in distribution systems due to low cost, simplicity, reliability, and control-less operation [3-5]. These filters are tuned to attenuate certain harmonics present in the line current. However, passive filters suffer from the problem of mistuning for load perturbations and may introduce resonance into the power system [6].

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Active filters offer a flexible alternative through the use of series or shunt-connected power converters. Active filters generate voltage/current waveforms, which cancel the harmonics of the nonlinear loads. As compared to their passive counterparts, active filters do not suffer from mistuning and can compensate all harmonics with a fast control response [7-9]. However, cost, complexity, and reliability are considered the major drawbacks of active filters.

Fuzzy system methodology has been demonstrated to allow solving uncertain and vague problems [10], [11]. Example applications for power quality and power systems are included in [12]

In this paper, a fuzzy-logic is introduced. A fuzzy-logic-based approach is proposed to control the harmonic using Mamdani's fuzzy inference mechanism. The advantages of using a fuzzy system are simplicity, ease of application, flexibility, speed and ability to deal with imprecision and uncertainties.

The proposed approach is tested for linear and nonlinear loads supplied from sinusoidal and/or nonsinusoidal sources while considering lagging and leading power factor.

The proposed fuzzy logic can successfully be applied for evaluating the power quality while considering distorted waveforms. The proposed fuzzy logic as an essential fuzzy module in that application for evaluating the power factors while aggregating it with other modules outputs such as voltage total harmonic distortion and total demand distortion.

2. Fuzzy set theory and fuzzy inference systems

2.1 Fuzzy Set Theory

The concept of the fuzzy set introduced by Zadeh [10] is a set without precise boundaries. In contrast a classical set or a crisp set has boundaries that are known precisely. Elements of a fuzzy set belong to it with a certain degree, also called degree of membership, that ranges from 0 to 1 while in crisp set it is only 1 or 0 which means "belong to" or "does not belong to". The degree of membership is a result of mapping the input space also called universe of discourse using a membership function.

If X is the universe of discourse, then a classical (crisp) set is expressed as

$$A = \{x|_{x>5}\} \tag{1}$$

A fuzzy set B is defined as a set of ordered pairs

$$B = \{x, \mu_B(x)|_{x\in X}\} \tag{2}$$

Here, $\mu_B(x)$ is the membership function of the fuzzy set B.

In addition, fuzzy logic was introduced as a superset of standard Boolean logic by considering the fuzzy values that range from 0 to 1 instead of only two values true or false and applying the same logic operators such as and, or not etc. Thus the concept is extended from two valued logic to multi-valued logic, which have many applications [13].

Using fuzzy logic, it is easy to formulate the conditional statements called IF-THEN rules [14]. These rules consist of two parts: 1) the condition part also known as premise, antecedent, or the IF part and 2) the action part also called the consequent or the THEN part. The IF-THEN rule can take the following form:

IF x is A THEN y is B

where A, B are linguistic variables, which are variables whose values are sentences in a natural language.

2.2 Fuzzy Inference Systems

The process which maps the given input into the output using fuzzy logic is known as fuzzy inference. Any fuzzy inference system can be simply represented in four integrating blocks as shown in Fig. 1.

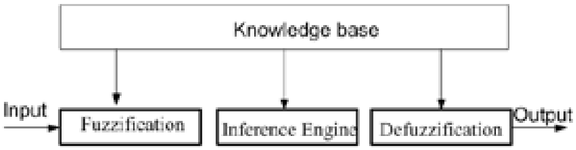

Figure 1. Schematic diagram of a fuzzy inference system

Fuzzification: is the process of transforming any crisp value to the corresponding linguistic variable (fuzzy value) based on the appropriate membership function. Knowledge base: contains membership functions definitions and the necessary IF-THEN rules. Inference engine: this simulates human decision making through using implication and aggregation processes.

Defuzzification: is the process of transforming the fuzzy output into a crisp numerical value.

3. Fuzzy inference system implementation

This section explains the fuzzy logic-based approach utilized to calculate the amalgamation of the existing power factors, displacement power factor, transmission efficiency power factor, and oscillation power factor. This module was built using Fuzzy Logic Toolbox available in Matlab 7.3. The design procedure is as follows:

3.1 Input and Output Fuzzification

The displacement power factor, transmission efficiency power factor, and oscillation power factor are used to be inputs. The values of the displacement power factor and transmission efficiency power factor range between 0 and 1 while those of the oscillation power factor range between 0 and 0.816.

We use the triangular form for the membership functions due to its simplicity to represent input variables, and three linguistic variables, Low, Medium, and High. The output are seven linguistic variables; Low, Moderately Low, Somewhat Low, Medium, Somewhat High, Moderately High, and High.

3.2 Fuzzy Inference Mechanism

Mamdani's fuzzy inference mechanism that is used here, is commonly used, in which the implication part is modeled by means of the minimum operator while the aggregation part is processed using the maximum operator.

3.3 Output Defuzzification

There are many defuzzification techniques in the literature [11].We use the center of area or center of gravity method. This method returns the center of area under the curve that results from the aggregation process.

For given values of the displacement power factor, transmission efficiency power factor, and oscillation power factor, the fuzzy inference system module will calculate the power factor. Note that, the ideal case corresponds to the sinusoidal linear load while the nonideal case corresponds to any other case than the sinusoidal linear load.

4. Applications and results

The fuzzy inference system is applied to different test cases that include linear and nonlinear loads supplied from sinusoidal and nonsinusoidal sources.

4.1 Linear Load Supplied From Sinusoidal Source

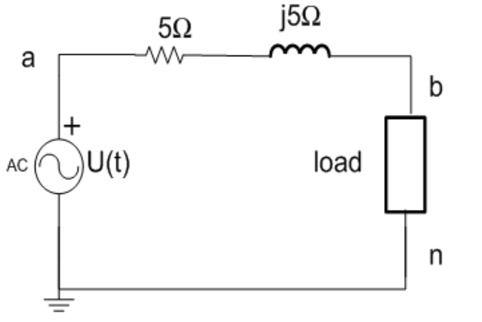

Figure 2. Linear supplied from sinusoidal or no sinusoidal source

Fig. 2 shows a circuit consisting of a linear load supplied from a sinusoidal source($f_1 = 50Hz$)through a line having an impedance of (5+j5) The source voltage has the following time domain equation:

$$u(t) = 100\sin 377t \tag{3}$$

The load voltage and the load current are used to calculate the displacement power factor, transmission efficiency power factor, and oscillation power factor.

Seven cases are considered here :case 1(R=1,X=0);case 2 (R=0,X=20); case 3(R=0,X=5); case 4(R=20,X=20);case 5(R=20,X=113);case 6(R=20,X=5); case 7(R=20,X=20).The values for these cases are chosen to represent different values of power factors to help explain and evaluate the new concept. Cases 2-6 represent lagging power factor while Case 7 represents the leading power factor. Once the concept fulfills all of the requirements previously determined, it can be applied to all other complex cases. The circuit chosen is intended to be simple to help explain and evaluate the new concept.

The simulation results show that Case 1 involving a pure resistive load results in coinciding values of the displacement power factor and transmission efficiency power factor, but the oscillation power factor is different because its maximum value is not one, but 0.816.

4.2 Linear Load Supplied From Nonsinusoidal Source

Referring to Fig. 2, when the source voltage is nonsinusoidal and contains in addition to the fundamental co- mponent, the third, fifth, seventh, ninth, eleventh, and fifteenth, the time domain equation for this source voltage could be written as [15]

$$\begin{aligned} u(t) &= 100\sin 377t + 81\sin 1131t + 60.6\sin 1885t \\ &+ 37\sin 2639t + 15.7\sin 3393t + 2.4\sin 4147t \\ &+ 6.3\sin 4900t + 7.9\sin 5654t \end{aligned} \tag{4}$$

By the results of simulation, it can be inferred that their results look similar except that in some cases the transmission efficiency power factor and the oscillation power factor give different results as expected since the loads are linear and the source is nonsinusoidal, and the representative quality power factor as a result try to track these changes.

4.3 Nonlinear Load Supplied From Sinusoidal Source

For a circuit consisting of nonlinear load, supplied from a sinusoidal source .At this moment the load voltage is the voltage across the whole nonlinear load. In this case, the situation is different. For example, considering case 1 of the pure resistive load with diode, the displacement power factor gives 1 while the transmission efficiency power factor gives a value less than one. This means that the power transmitted to the load is less than that generated although the load is purely resistive and there is no reactive element. Also the oscillation power factor is less than 0.816 which means that there is an oscillating power between the source and the load with zero average power, and this could explain why the transmission efficiency is not equal to one in this case.

4.4 Nonlinear Load Supplied From Nonsinusoidal Source

This is the case most likely to be encountered in practice. The load is nonlinear and the source is nonsinusoidal so, there is no coincidence between the displacement power factor values and the other power factor values which indicates the presence of oscillating power, and that the useful power transmitted to the load is less than the generated one in all loading conditions.

5. Conclusions

This paper presents an efficient method to control harmonic based on fuzzy logic and some basic concepts of fuzzy set theory and fuzzy inference systems are introduced in this paper.

Also, the use of fuzzy systems to calculate this factor has the advantage of being simple, easy to implement, flexible, can be easily altered, adjusted, and it contains its knowledge base so there is no need for an expert. The fuzzy logic proposed can be effective in making a cost-effective analysis for applying the power factor correction devices and power quality mitigation techniques. The fuzzy logic introduced in this paper can serve as a valuable reference for industrial professionals for selection of possible harmonic control methods and improve the power quality.

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